# Operation of Magnets in High Field Laboratory for Superconducting Materials of IMR



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| journal or publication title | Science reports of the Research Institutes, Tohoku University. Ser. A, Physics, chemistry and metallurgy |
| volume | 37 |
| number | 1/2 |
| page range | 1-6 |
| year | 1992-11 |
| URL | http://hdl.handle.net/10097/28386 |

# Operation of Magnets in High Field Laboratory for Superconducting Materials of IMR*

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(Received September 29, 1992)

Synopsis

This paper serves as a preface to the present special issue of Sci. Rep. RITU, describing the brief history and the present status of High Field Laboratory for Superconducting Materials (HFLSM), which reached the 10th anniversary last year. The HFLSM is equipped with steady-high-field magnets such as superconducting magnets, high-power water-cooled magnets and hybrid magnets. The facilities have been used for a variety of cooperative research programs. Some significant achievements in researches on superconducting materials appear in this issue, and another issue concerning various high-field researches will be published soon.

## I. Introduction

The Research Institute for Iron, Steel and Other Metals (RIISOM), the predecessor of the present Institute for Materials Research (IMR), had a long history of high-field magnets : a Kapitza-type pulsed magnet was constructed in 1939, producing a field of 27 T during 5 ms[1], and a Bitter-type magnet of 3 MW power was installed in 1957, generating a steady field of 10 T[2]. The latter was quite unique before a conventional superconducting magnet of the 10 T field became available.

In the end of 1970's, we faced an oil crisis and felt strongly the necessity of early development of nuclear fusion reactors which would require high-field superconducting magnets for the plasma confinement. The materials with high critical field and high critical current density should be tested in steady high fields which could not be produced by an existing superconducting magnet but by a high-power water-cooled magnet. A more efficient method to produce the highest field is the use of a combination of the outer superconducting magnet and the inner water-cooled magnet, called a hybrid magnet.

The hybrid magnet project of RIISOM was approved by Japanese Government in 1981, and the High Field Laboratory for Superconducting Materials (HFLSM) was established. Three types of hybrid magnets were constructed together with an 8 MW DC power supply and a corresponding water-cooling system. The largest hybrid magnet (HM-1) could produce a field of 30.7 T[3] in 1985, and the field amounted to 31.1 T[4] in 1986; these field values were the world records at those times, respectively. The HFLSM has also provided instruments for measuring electric and magnetic properties of test samples. Full details of the facilities in the year 1986 appeared

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*The 1884th report of Institute for Materials Research

in a special issue, named "Hybrid Magnet", of Sci. Rep. RITU[5]. More recent reports were presented at some international symposia on high magnetic fields[6,7,8]. The HFLSM remained unaltered when RIISOM was reorganized as IMR in 1987.

The facilities in HFLSM are open to visiting scientists and engineers. Cooperative research programs are under way on a nation-wide scale. The most important research subjects are superconducting materials, especially the high-temperature superconducting oxides since the epoch-making discovery in 1986. In addition, a variety of physical and chemical researches have been conducted using the high-field magnets.

At the 10th anniversary of HFLSM in 1991, it was planned that some important achievements should be published in new special issues of Sci. Rep. RITU. The present issue is devoted to the superconducting materials, and another issue on other researches will be published soon. This paper serves as a preface to this special issue.

## II. Outline of Facilities

Table I lists all the high-field magnets in HFLSM . This is somewhat different from that reported in the previous special issue of Sci. Rep. RITU[5]. We installed three hybrid magnets, HM-3, HM-2 and HM-1, in chronological order. The outer superconducting magnets are called SM-3, SM-2 and SM-1, respectively, and the inner water-cooled magnets are WM-3, WM-2 and WM-1. We have two kinds of water-cooled magnets WM-1a and WM-1b with different bores for HM-1. Recently WM-3 was removed from HM-3 so that SM-3 could be used as a large-bore superconducting magnet of the 8 T field. This magnet has proved quite useful for some chemical and

Table I. Magnets in HFLSM

| Magnet | Effective bore (mm) | Center field (T) | Power (MW) | Current (A) | Type |
|---|---|---|---|---|---|
| HM-1 | 32 or 52 | 31 or 28 | Combination of SM-1 and WM-1a or b | | |
| SM-1 | 360 | 12 | - | 1456 | NbTi-$Nb_3Sn$ (pancake) |
| WM-1a | 32 | 19 | 7.4 | 22500 | polyhelix |
| WM-1b | 52 | 17 | 7.0 | 22300 | polyhelix |
| HM-2 | 52 | 23 | Combination of SM-2 and WM-2 | | |
| SM-2 | 360 | 8 | - | 1470 | NbTi (pancake) |
| WM-2 | 52 | 16 | 6.3 | 21400 | double Bitter |
| SM-3 | 220 | 8 | - | 780 | NbTi (layer-wound) |
| 15T-SM | 52 | 15 | - | 99 | NbTi-$Nb_3Sn$ (fm) |
| 13T-SM | 50 | 13 | - | 150/450 | NbTi/$Nb_3Sn$ (fm) |
| 9T-SSM | 25 | 9 | - | 150 | $Nb_3Sn$ (tape) |
| WM-4 | 32 | 17 | 4.1 | 17500 | Bitter-polyhelix |
| WM-5 | 82 | 15 | 6.7 | 20900 | Bitter |
| WM-6 | 62 | 12 | 4.6 | 13700 | Bitter |

HM : hybrid magnet, SM : superconducting magnet, WM : water-cooled magnet
SSM : split-type SM (19 mm gap), horizontal field

biological experiments.

The 15 T-SM in Table I, having multifilamentary $Nb_3Sn$ windings, is a substitute of the 16.5 T-SM with $Nb_3Sn$-tape windings. The latter was installed in 1982 and operated more than 180 days every year until 1991, resulting in some deterioration. The new 15 T-SM is more convenient for most experiments because of a faster sweep rate of the field. Both 13 T-SM and 9 T-SSM manufactured in early 1980's are still in active service.

We have three kinds of non-hybrid water-cooled magnets, WM-4, WM-5 and WM-6. The Bitter-type large-bore magnet, WM-5, has most frequently been used during the past 10 years. The WM-4 consisting of an outer Bitter coil and an inner polyhelix coil will be able to produce a field of 20 T, although the field has been limited to 17 T for safety. The high-homogeneity Bitter magnet, WM-6, has scarcely been used because of the low value of maximum field.

The DC power supply for the water-cooled magnets has the following characteristics: 8 MW power with 350 V and 23 kA, the current ripple less than $1 \times 10^{-4}$ rms, and the current stability $1 \times 10^{-4}$ for 3 hrs at full power. Sometimes, however, we are suffered from a large flicker noise caused by an industrial arc furnace which shares the city power station with us. We are making an effort to avoid this noise, but the situation is still unsatisfactory at present. The water-cooling system consisting of turbo-refrigerators and cooling towers has been working quite satisfactory. Very recently, however, we have encountered an environmental problem concerning the turbo-refrigerator; chlorofluorocarbon (CFC) should be replaced by another refrigerant to protect the earth's ozone layer from depletion.

The cooling down of the large superconducting magnets requires an elaborate cryogenic system. Phillips' cryogenerators (PGH 105) for pre-cooling both SM-2 and SM-3 are working well after a careful maintenance every year. A sufficient amount of liquid helium is supplied by Sulzer's liquefier with a capability of 100 l/h. On the other hand, the SM-1 is directly cooled down by another liquefier-refrigerator with capabilities of 35 l/h and 100 W at 4.5 K.

## III. Operation of Magnets

The high-power DC supply and the water-cooling system are operated from 9 a.m. to 8 p.m. on Monday, Wednesday and Thursday and from 9 a.m. to 5 p.m. on Tuesday and Friday. Either HM-1 or HM-2 is operated for two successive weeks every month, and other weeks are devoted to operate one of the non-hybrid water-cooled magnets, mainly WM-4 or WM-5. Instead, however, WM-1a, WM-1b or WM-2 is sometimes operated without the corresponding superconducting magnet in order to realize the same arrangement of measuring system as that for the hybrid magnet.

It takes about a week to cool down SM-1 and SM -2 from room temperature to 4.2 K. The field-sweep rate of the superconducting magnet is much lower than that of the water-cooled magnet. Thus the running time of the hybrid magnet should be strictly limited, and the lower-field measurement should be made with a non-hybrid water-cooled magnet or a non-hybrid superconducting magnet. The non-hybrid superconducting magnet is operated indepently, except for the SM-3 which can be used only when neither HM-1 nor HM-2 in the same room is operated. Other superconducting magnets can be operated even on holidays.

The operation of the water-cooed magnet, on the other hand, is strictly controlled by operators. Table II lists numbers of operation times and electric power consumptions of the water-cooled magnets. We define the number of operation times as the number of the field sweep up to the maximum field of the magnet. The electric power consumption is the sum total for the period of operation.

Since a resistive coil of the water-cooled magnet has a limited longevity, we have to replace the coil rather frequently. Usually we have prepared a spare coil so as to make the quick replacement. As an example, the numbers of operation times and electric power consumptions of the Bitter coils of WM-5 are shown in Table III. We manufactured five coils (No.1~No. 5); the coils No.1, No.3 and No.4 were burnt out, the coil No.2 has been used repeatedly after slight modifications, and the coil No.5 is the spare coil, not appearing in Table III. The mean life time of the Bitter coils of WM-5 exceeds two years.

In summer the high-power DC supply is stopped for 3 weeks in order to relieve an electric power shortage of the city power station. These weeks are devoted to the

Table II Number of operation times and electric power consumption of water-cooled magnets

| Magnet | Period* | Number of operation times | Electric power consumption (MWh) |
|---|---|---|---|
| Hybrid | | | |
| WM-1a | 1984 - 1991 | 141 | 398 |
| WM-1b | 1983 - 1991 | 481 | 1565 |
| WM-2 | 1983 - 1991 | 1578 | 3926 |
| WM-3 | 1983 - 1986 | 92 | 112 |
| Non-hybrid | | | |
| WM-4 | 1990 - 1991 | 489 | 116 |
| WM-5 | 1984 - 1991 | 8355 | 5758 |
| WM-6 | 1984 - 1985 | 96 | 373 |

* The fiscal year, extending from April to March of the next year

Table III Number of operation times and electric power consumption of Bitter coils of WM-5

| Coil | Period | Number of operation times | Electric power consumption (MWh) |
|---|---|---|---|
| No.1 | May 1984 - Mar. 1985 | 391 | 310 |
| No.2 | Apr. 1985 - Oct. 1985 | 311 | 217 |
| No.3 | Oct. 1985 - Dec. 1987 | 3185 | 2054 |
| No.2 | Dec. 1987 - Mar. 1990 | 3046 | 2031 |
| No.4 | Apr. 1990 - Feb. 1992 | 1391 | 1120 |
| No.2 | Mar. 1992 | 31 | 26 |
| | Total : | 8355 | 5758 |

maintenance and inspection of the facilities. We have also long holidays in New Year and so-called Golden Week in May. The facilities are running, however, for over 200 days per year.

## IV. Concluding Remarks

The facilities in HFLSM have been utilized by many scientists and engineers coming from national and private universities as well as governmental and industrial laboratories throughout Japan. Users from the universities include graduate and undergraduate students, so the HFLSM has made a great contribution to the education. Table IV lists the number of bachelor, master and doctor theses in which experimental results using the high-field magnets in HFLSM are described.

All the achievements in HFLSM were reported in Japanese in the Annual Report since 1984. The 1991 Report contains 91 papers, of which 18 papers are concerned with the superconductivity research without high-field magnets. Others are the high-field researches classified as follows : 19 papers on superconducting oxides, 14 papers on conventional superconductors, 17 papers on magnetism, 5 papers on optical properties, 5 papers on chemical and biological effects and 9 papers on miscellaneous properties. In addition, 4 papers deal with magnet technology and measuring techniques. Although most of these papers have also been submitted to current journals or conference proceedings in English, it is thought to be worthwhile to publish this special issue written in English.

At the 10th anniversary of HFLSM, although the English name remained unaltered, the Japanese name was changed in order to renew the administration structure of this laboratory. The literal translation of the new Japanese name is the Research Center

Table IV Number of bachelor (B), master (M), and doctor (D) theses in which the experimental results obtained in HFLSM are described.

| Year | Science | | | Engineering | | | Medicine |
|---|---|---|---|---|---|---|---|
| | B | M | D | B | M | D | D |
| 1982 | | 1 | | | | | |
| 1983 | | 1 | | | 1 | | |
| 1984 | | 2 | | | 4 | | |
| 1985 | | 4 | | 2 | 3 | | |
| 1986 | | 5 | | 1 | 5 | | |
| 1987 | | 4 | 2 | 4 | 9 | 1 | |
| 1988 | | 5 | 1 | 2 | 8 | | |
| 1989 | 1 | 11 | 2 | 4 | 13 | 1 | 1 |
| 1990 | 1 | 9 | 2 | 7 | 13 | | |
| 1991 | 3 | 5 | 1 | 7 | 12 | 5 | |
| Total | 5 | 47 | 8 | 27 | 68 | 7 | 1 |

of High Magnetic Field Superconducting Materials, affiliated to IMR, Tohoku University. This Research Center will be maintained at least until March, 2001.

## Acknowledgments

I wish to express sincere thanks to all persons who have been supporting the development of HFLSM, especially to Professor T. Masumoto, Director of IMR. I am greatly indebted to Professor Emeritus Y. Muto, former Director of HFLSM, for his tremendous efforts to establish the laboratory and to promote the research project. Thanks are also due to all staff members of HFLSM, Profs. G. Kido, K. Watanabe, A. Hoshi and S. Miura, and Dr. T. Sasaki and Mr. S. Awaji. Messrs. M. Kudo, K. Sai and Y. Ishikawa are acknowledged for the operation of high-field magnets, and Messrs. S. Ohtomo, H. Miura, S. Tanno, Y. Ishigami and K. Hosokura for the cryogenic operation. I am also thankful to Misses C. Shibata and K. Iijima for preparation of this special issue.

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